Monte Carlo Simulation of Age-Dependent Host-Parasite Relations

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Abstract: The death of a biological population is an extreme event which we investigate here for a host-parasitoid system. Our simulations using the Penna ageing model show how biological evolution can "teach" the parasitoids to avoid extinction by waiting for the right age of the host. We also show the dependence of extinction time on the population size.

The death of a biological population is an extreme event [1] which we investigate here for a host-parasitoid system. (Parasites let the host survive, parasitoids eventually kill the host. In the following both are called parasites.) For seasonal hosts (plants or animals) the parasites can survive only if they parasitise the right developmental stage (egg, larva, pupa, imago) of their host. Therefore they have to attack their host at the right time, i.e. at the right age of the host or the respective right month of the year [2]. Earlier the host has not yet accumulated enough resources, unsuitable for an attack of a parasite. Biological evolution thus should ensure that the parasites "know" what the proper age of the host or time of the year is. The present note aims to check if such an evolutionary self-organization can be simulated; we do not deal with the process how the parasites recognise the age of the host or the month of the year.

One example are diversified host-parasite-systems: Endoparasites deposit their eggs in the interior of the host animal, and thus in case of young host larvae for example they have to wait until the host has developed enough. Then they compete with ectoparasites attacking the host animal from the outside. Thus the consideration of the age of the individuals is important, similar to the 'just in time' philosophy in logistics. We will simulate both fluctuations in equilibrium (normal case), and possible extinction (extreme event) and thus will find the border between extinction and survival.

We use the standard asexual Penna ageing model of mutation accumulation, with reproduction starting an age of 8 time intervals, using a "genome"

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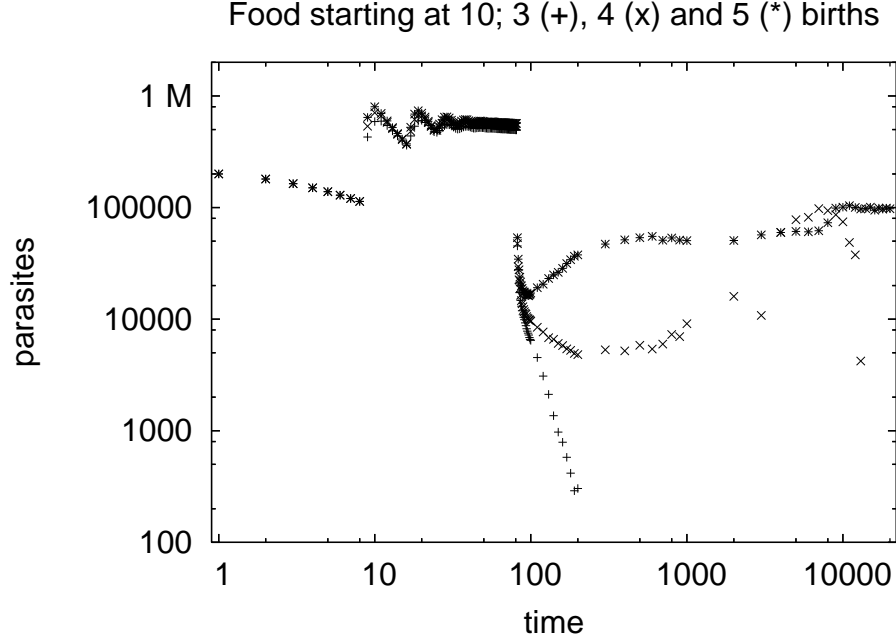Food starting at 10; 3 (+), 4 (x) and 5 (*) births

Figure 1: Time dependence of number of parasites near threshold for extinction, for birth rates 3, 4 and 5.

of 32 bits representing at most 32 time intervals of the life, with 3 set active bits (bad mutations) killing the individual, and a Verhulst factor killing at all ages because of overpopulation. At each iteration, each mature host produces three and each mature parasite produces B offspring. At each birth, one random mutation is made for all offspring by flipping a randomly selected bit from 0 (healthy) to 1 (sick). (If it is 1 already it stays at 1: no new mutation.) Typically, 10^4 iterations were averaged over after the populations had reached roughly a dynamic equilibrium of births and deaths. More details on the Penna model of 1995 are given in many articles and two books [3], The border between extinction and survival was investigated in [4] without host-parasite relations.

With this standard model, hosts and parasites are simulated together, using separate Verhulst factors with the same carrying capacity. In contrast to the hosts, the parasites at each iteration make 100 attempts to invade a host of their desired age. (These desired host ages are at the beginning
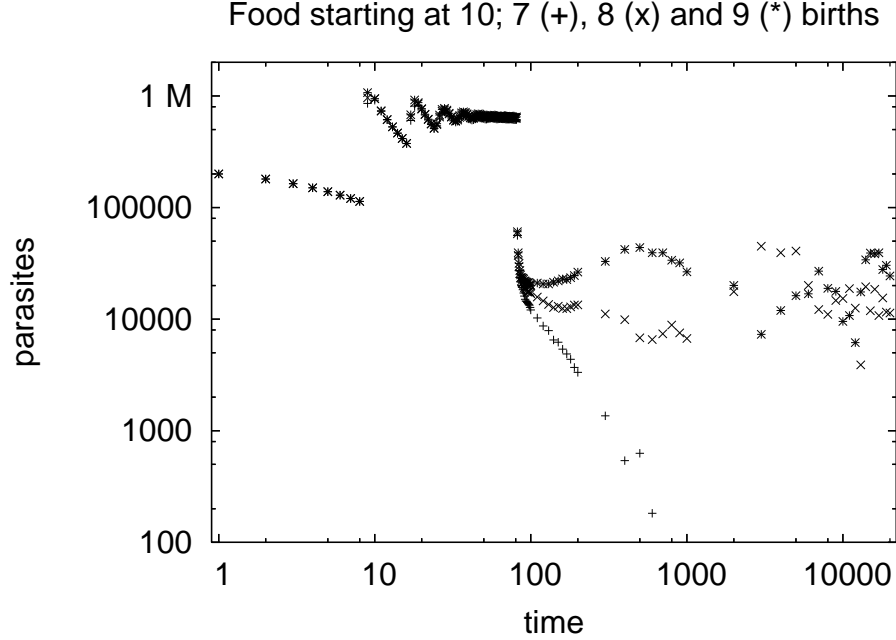
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Figure 2: As previous figure but with continuous mutations of desired host ages, and birth rates 7, 8 and 9.

distributed randomly between zero and 31.) If all 100 attempts were unsuccessful, they die. Otherwise they have enough food provided the host age is at least 10, slightly above the minimum reproduction age of 8. If the host is too young, then again the parasite dies; if not it survives and ages.

In some simulations we also mutated, randomly and continuously, the desired host age. Then at birth of a parasite, not only the usual bit-string genome is mutated but also its desired host age. With 25 percent probability it increases by one unit, with 25 percent probability it decreases by one unit, and in the remaining 50 percent of the cases it stays constant.

Parasites do not necessarily affect the health of the host [2], and we neglect this influence completely. Generally, if we look at the boundary between survival and extinction of the parasites, the influence of the parasites becomes zero at this boundary.

In the simulations we first make 80 iterations without coupling hosts and parasites, in order to get close to a stationary state; see left parts of Figs.1,2.
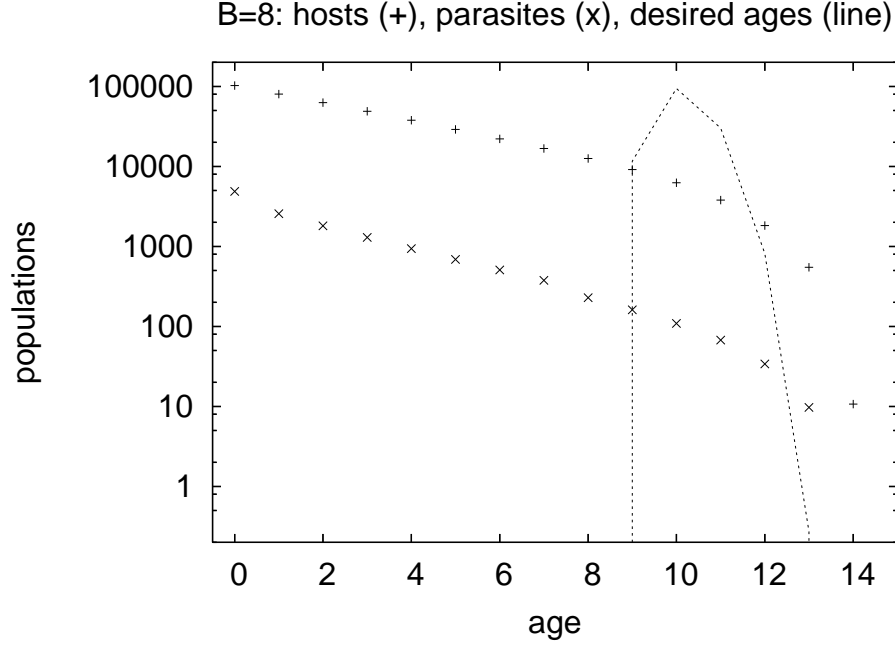
Figure 3: Summed age distribution of hosts (+) and parasites(x), and histogram (line, divided by 1000) of desired age, for continuous mutations of desired food ages. Without these mutations the histogram is nonzero only at age = 10, while the age distribution is about the same. Initially, the histogram is flat between ages 0 and 31.

From then on the parasites need a host of the proper age, and thus most of them die. The question is whether some survive nevertheless and replenish the parasite population.

Figure 1 shows the time dependence of the populations without and Fig.2 with the continuous mutations of the desired host ages. With these mutations, Fig.3 shows the age distributions (as usual for the Penna model) and the distribution of the desired host ages. The latter one changes from its initial flat shape between the possible ages zero and 31, to a narrow peak close to the minimum age of 10 where hosts become useful for the parasites. If the mutations of the desired host ages are omitted, the distribution becomes a delta function at age = 10. On an expanded time scale, Fig.4 shows the rapid transition from a flat to a sharply peaked distribution, within a
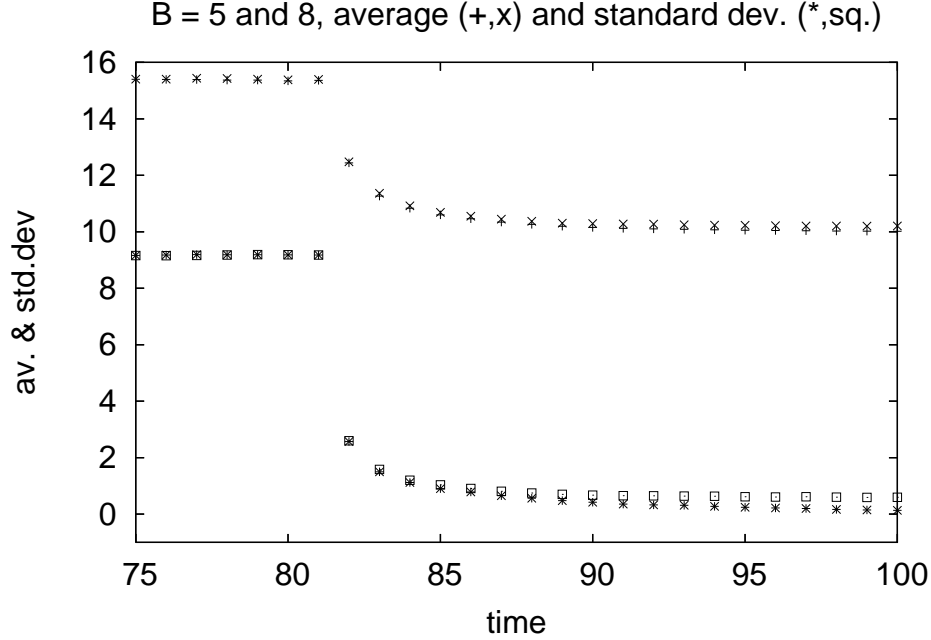
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Figure 4: Time dependence of the average desired age and its standard deviation shortly before and after the parasites start to select hosts according to host age. Birth rate 5 without and birth rate 8 with continuous mutation of desired host age; these mutations keep the standard deviations above zero.

few iterations. Usually in reality, as opposed to the above simulations, the parasites are smaller and more numerous than the hosts. We now achieve this by making the parasite carrying capacity 10 times bigger than that for the hosts, Fig.5.

When we demand that the host age is not only at least 10 but exactly a fixed age than this age has to be fixed at unrealistically low ages (not shown).

Small populations subject to random fluctuations always die out if observed long enough[5]. "Small" means here than the fluctuations in the population size are much smaller than the average population size. Fig.6 shows in a comparison of three population sizes that the host populations fluctuate relatively less when the population size is increased, and do not die out. The parasite populations, on the other hand, behave differently, and die out even when on average they number tens of thousands. The reason is that in
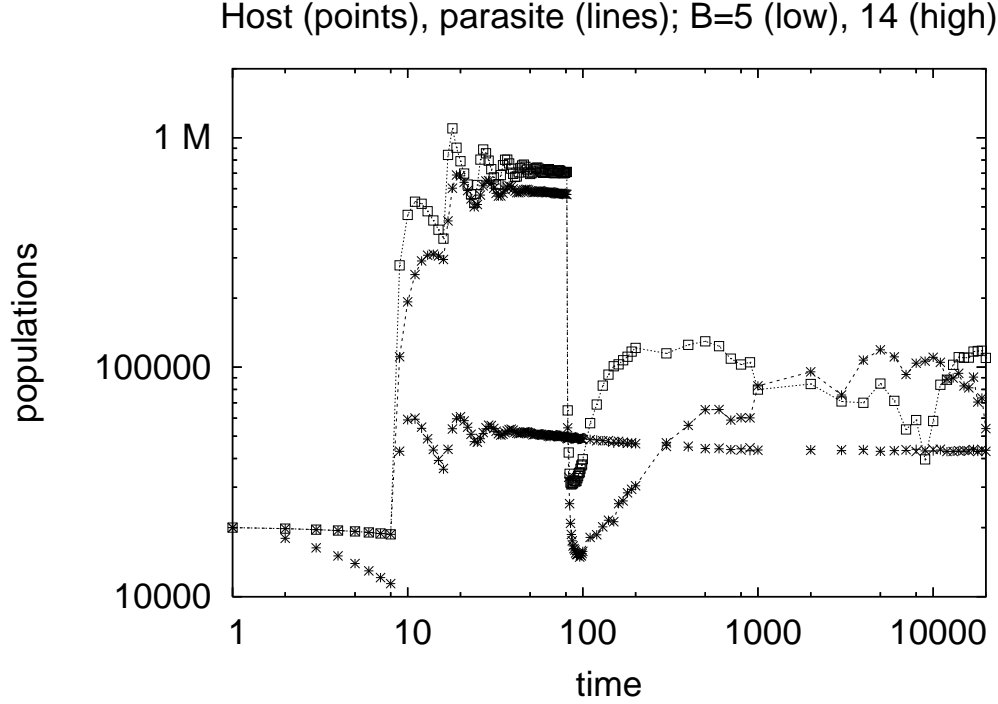
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Figure 5: Time dependence of the number of hosts (separate symbols) and parasites (lines with stars and squares) without (B=5,*) and with (B=17,sq.) continuous mutations of the desired host ages.

contrast to Fig.5 with $B = 17$ we took for Fig.6 a lower birthrate of 10, close to the boundary between survival and extinction of the parasites.

In summary, we simulated how natural evolution via survival of the fittest can "teach" the parasites to avoid extinction by attacking hosts at the proper host age (or time of the year for seasonal hosts). In the future one could simulate more explicitely different life strategies of the parasites, e.g. endoparasitoids versus true parasite for plants or animals.

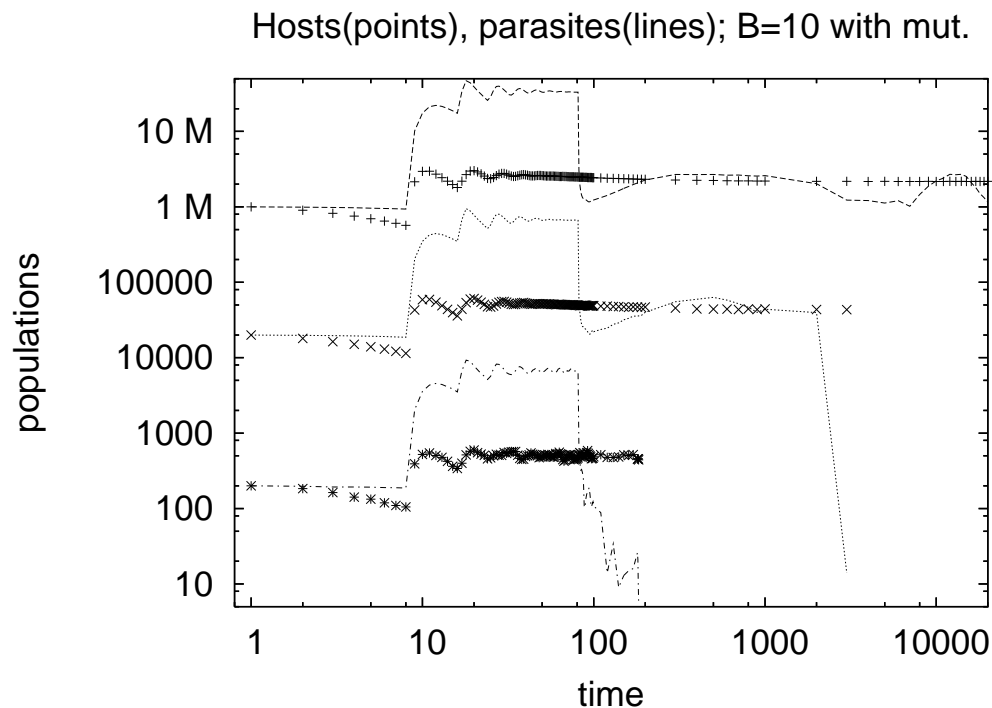This note is dedicated to Naeem Jan with whom DS started ageing simulations.

6

Figure 6: Time dependence of the number of hosts (separate symbols) and parasites (lines with stars and squares) with continuous mutations of the desired host ages and $B = 10$ close to the extinction value. Three population sizes are showsn, differeing by two and four decades.

References

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